Efficient OLED fabricated by all wet process using alcohol-soluble and wide energy gap organic semiconductor

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ABSTRACT

We demonstrated highly efficient OLED fabricated by all wet process employing the electron transporting material, called DYETM-4. DYETM-4 has wide energy gap of 4.26 eV. The all wet processed OLED using electron transporting DYETM-4 exhibited efficient EL performance; maximum current efficiency η_{max} was evaluated to be 41.7cd A^{-1} (an external quantum efficiency = 11.6%) at an applied voltage of 9 V at a luminance of 57.4 cd m^{-2}.

INTRODUCTION

In organic light-emitting diodes (OLEDs), extreme improvement of electroluminescence (EL) quantum efficiency was brought about by the employment of multi-layered structures of organic semiconductors [1,2]. In addition, employment phosphorescence materials as emissive material provided further advance in EL efficiency through improvement external quantum efficiency by using luminescence from triplet-exited state.[3,4]

Wet process, in which films of organic semiconductors are prepared from their solutions [5,6], is expected to be a promising manufacture process of OLED because application of ink-jet printing technique to the wet process makes low-cost production of large-size and high-resolution OLEDs display possible. However, this process has difficulty in constructing multi-layered structure. For preparation of multi-layered OLED with well-defined structure by using wet-process, therefore, it is indispensable to develop organic semiconductors having large difference in solubility [7,8,9].

In this work, we demonstrated efficient OLED fabricated by all wet process using alcohol-soluble organic semiconductors having electron-transporting and hole-blocking properties. In this presentation, we will report film qualities and photo-electric property of the alcohol-soluble organic semiconductors, device performance of the OLED fabricated by all wet process.

EXPERIMENTAL

In this work, We employed poly(3,4)ethylenedioxythiophene - polysthrenesulphonate (PEDOT-PSS) [6] as hole injection layer, poly(9-vinylcarbazole) (PVCz) doped with tris(2-phenylpyridine)iridium ($Ir(ppy)_3$) guest as hole-transporting and emissive layer [4] and organic semiconductor, named DYETM-4, as electron transporting layer. Organic layers of PEDOT-PSS (45nm), PVCz doped with 6.8 wt% $Ir(ppy)_3$ (60nm) and DYTEM-4 (30nm) were prepared by spin-coating from aqueous solution, tetrahydrofuran solution, and 2-propanol solution, respectively. These films were fabricated in N_2 atmosphere. The films of PEDOT-PSS, PVCz:$Ir(ppy)_3$ and DYETM-4 were dried in a dry oven at 120 °C, 70 °C and 95 °C, respectively. Then, lithium fluoride (0.5nm) and aluminum (100nm) film were successively vacuum-deposited as a cathode. For the comparison, tri-layered device having a vacuum-deposited DYETM-4 layer (30nm) was also prepared.

RESULT AND DISCUSSION

The glass transition temperature and energy gap of DYTEM-4 was evaluated to be 149 °C and 4.26 eV by DSC measurement and absorption edge of spin-coated film, respectively. In addition, the electron affinity of DYTEM-4 was evaluated to be 2.74 eV by cyclic voltammetry measurement.

The film quality of spin-coated DYETM-4 films was evaluated by Atomic force microscope (AFM). For surface roughness, the arithmetic mean deviation of the surface profile (Ra), ITO/PEDOT-PSS/PVCz:$Ir(ppy)_3$ film was 0.7 nm. Those of wet and dry processed ITO/PEDOT-PSS/PVCz:$Ir(ppy)_3$/DYETM-4 films were 0.2 nm and 0.5nm, respectively.

In the all devices, green EL due to phosphorescence from $Ir(ppy)_3$ doped in the PVCz layer was observed. The EL spectra corresponded with phosphorescent spectrum of $Ir(ppy)_3$ peaking at 515 nm.

Figure 1 shows applied voltage – EL intensity characteristics of all wet processed OLED using DYTEM-4 and device with vacuum-deposited DYETM-4 film. The values of driving voltage of the devices at 100cd m^{-2} were relatively high comparing that of the device using $Ir(ppy)_3$ doped CBP as emissive layer; 9.6V for the all wet process device, 10.2V for device using vacuum-deposited, and 3.5 V for the device using $Ir(ppy)_3$ doped CBP[10]. The relatively high driving voltage may be due to low carrier mobility of the PVCz film.

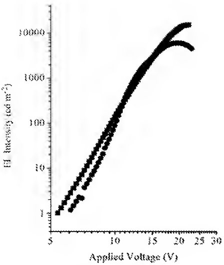

Fig. 1 Applied voltage – EL intensity characteristics of all wet processed OLED (square) and dry processed OLED (circle).

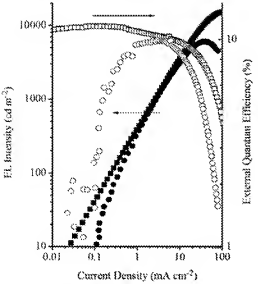

Fig. 2 Current density – EL intensity and external quantum efficiency characteristics of wet processed OLED (square) and dry processed OLED (circle).

In figure 2, current density – EL intensity and external quantum efficiency characteristics were shown. The value of maximum current efficiency η_{max} of the all wet processed device was enhanced comparing to that of the device with DYETM-4 film fabricated by vacuum vapor deposition; η_{max} = 41.7 cd A^{-1} (9 V, 57.4 cd m^{-2}, an external quantum efficiency Φ_{EX}= 11.6%) for the all wet processed device with DYETM-4 layer whereas η_{max} = 35.4 cd A^{-1} (14V, 2113 cd m^{-2}, Φ_{EX} = 9.8%) for the device with vacuum-deposited DYETM-4. Maximum EL intensity of the all wet process device was over 15,000cd m^{-2}. In addition to high hole-blocking capability of DYETM-4, higher triplet state (T_1) energy level of DYETM-4 is most likely to provided the high EL performance. The T_1 of DYETM-4 and $Ir(ppy)_3$ were evaluated to be 2.64eV and 2.3eV[11] by the phosphorescence peak, respectively. The triplet energy transfer from $Ir(ppy)_3$ to DYETM-4 was not occurred because the T_1 of DYETM-4 was higher than $Ir(ppy)_3$. As a result, highly efficient EL was attained.

CONCLUSION

We successfully prepared high efficient OLEDs by all wet process using alcohol-soluble organic semiconductor, DYTEM-4. In all wet processed device using DYTEM-4 as electron transporting layer, ITO/PEDOT-PSS/PVCz:$Ir(ppy)_3$/DYTEM-4/LiF/Al, highly efficient green EL was demonstrated. The internal quantum efficiency over 50% was suggested by the external quantum efficiency observed. The good EL performance of the all wet processed device demonstrated that DYTEM-4 has good electron-injection, electron-transporting and hole-blocking capability.

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